Engineering Reliability Modeling for Economic Analysis of Navigation Structures

David M. Schaaf, P.E.
LRD Regional Technical Specialist
(Louisville)

Purpose of Presentation

Describe how engineering reliability information is used in the economic evaluation of USACE infrastructure for Major Rehab Reports and other critical infrastructure decision-making studies

Examples of USACE Infrastructure

- Harbor Breakwaters
- Hydropower Facilities
- Flood Control Dams and Levees
- Flood Walls and Pumping Stations
- Bridges and Other Infrastructure
- Navigation Locks

Why is Risk and Reliability Used?

Required by USACE Guidance for the Justification of Specific Types of Investments

- Major Rehabilitation Projects
- New Projects Authorizations Based Upon Deteriorated Condition of Existing Project
- Systems Studies Authorizations and Recommendations

Recognizes and Captures Uncertainty in Engineering and Economic Analysis

Shows Economic Justification and Risks Associated with Multiple Investment Strategies

Allows for a Method to Rank Projects Based Upon Risks and Economic Merit

USACE Risk and Reliability Applications

Navigation-Related Evaluations

Major Rehabilitation Evaluations

- Markland Locks & Dam (fatigue/corrosion of lock miter gates and culvert valves)
- Emsworth Dam (fatigue/corrosion of dam gates and life cycle use of operating machinery)
- J.T. Myers Dam (erosion of dam stilling basin)

New Projects Authorizations Due to Deterioration of Existing Structure

- Chickamauga Lock Replacement Project (mass concrete deterioration due to alkali aggregate reaction)

Navigation Systems Studies

- Ohio River Mainstem Systems Study (19 sites – 38 locks)
- Great Lakes and St. Lawrence Seaway Navigation Study (18 locks with associated bridges, ports, etc…)

USACE Risk and Reliability Applications

Non-Navigation Evaluations

Flood Control Damage Reduction Evaluations

- Establish height of flood wall for various flood levels
- Assess risk of damage for various return period events

Coastal and Harbor Facilities

- Rehabilitation of breakwater structures

Hydropower Facilities

- Time the rehabilitation and replacement of hydroelectric power infrastructure (generators, gates, etc…)

Risk Assessment to Improve Process and Procedures

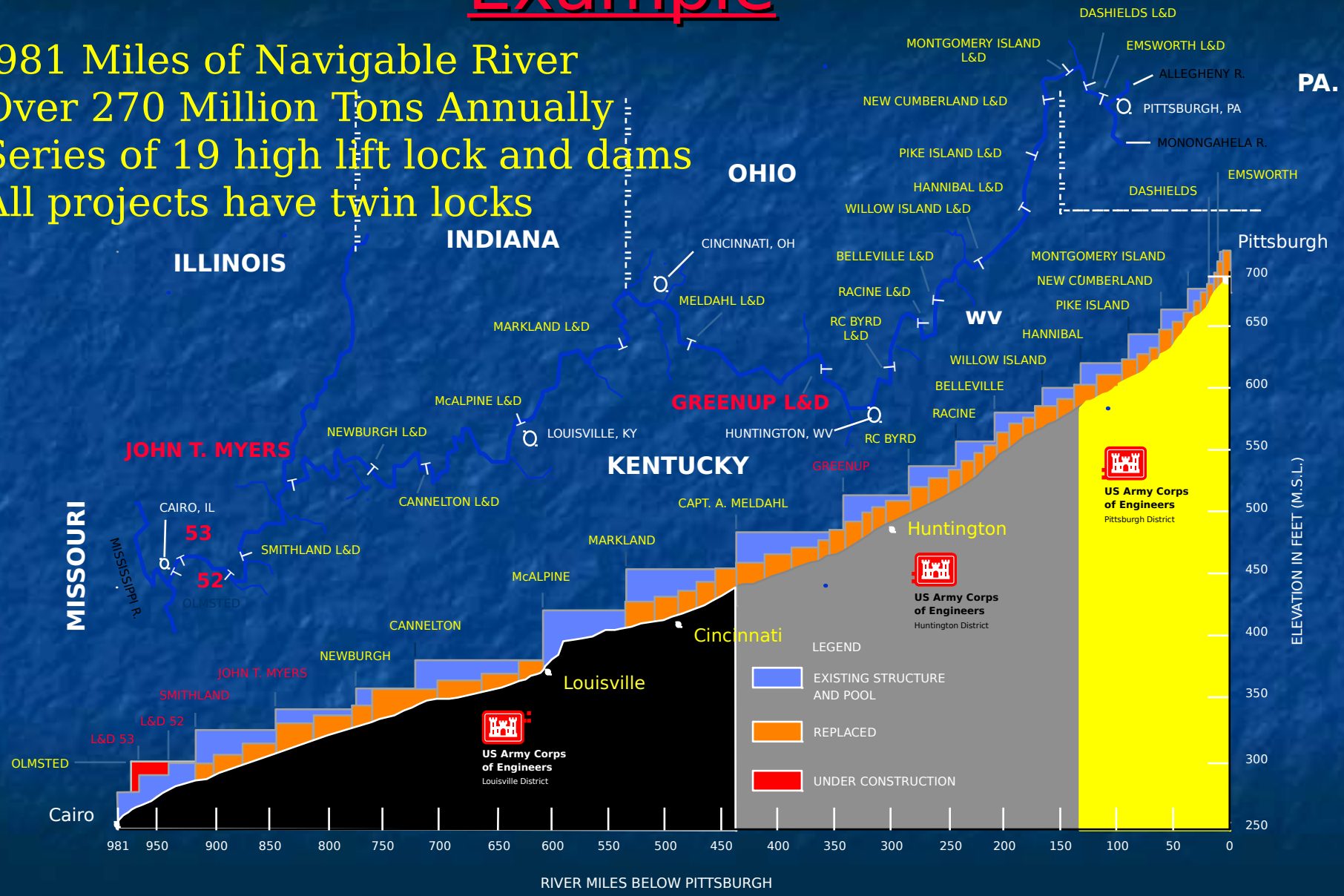
- Innovative construction (Braddock Dam float-in sections)
- Approach wall selection type (Lindy C. Boggs Lock and Dam)

Investment Tool for Decision-Making

- Measures the economic risk associated with performance of a component and/or system
- Reliability model itself is just one piece of the overall analysis. Must integrate with other aspects of the evaluation (plan formulation, economics, etc…)
- For an overall project, all key components are analyzed to determine their performance through the study period (typically 50 years)
- “Key” components are defined as any major component/structure that is either very costly to replace/rehab or its unsatisfactory performance would cause significant interruption of service

Ohio River System – Navigation Example

- 981 Miles of Navigable River
- Over 270 Million Tons Annually
- Series of 19 high lift lock and dams
- All projects have twin locks



Navigation Systems Modeling

Example – Ohio River Mainstem System Study

- STUDY OF ALL OHIO RIVER LOCK AND DAMS FOR TIME FRAME OF YEARS 2000 - 2060. THERE WILL BE 19 PROJECTS DURING STUDY PERIOD.

- SEVERAL SITES WILL BE SIGNIFICANTLY PAST THEIR DESIGN LIFE BY YEAR 2060. DESIGN LIFE IS TYPICALLY 50 YEARS FOR PROJECTS.

- STUDY OUTPUT WILL DEVELOP A MASTER INVESTMENT PLAN THAT OPTIMIZES AVAILABLE FUNDING AMONG MAINTENANCE, MAJOR REHABILITATION, AND NEW PROJECTS

Navigation Systems Modeling

Example – Ohio River Mainstem System Study

- OLDER, DETERIORATED PROJECTS NEED CONDITION ENHANCEMENTS (UPPER OHIO)
- HIGH-TRAFFIC PROJECTS NEED CAPACITY ENHANCEMENTS (MIDDLE AND LOWER OHIO)
- RELIABILITY IS USED TO JUSTIFY AND TIME BOTH CONDITION-BASED AND CAPACITY-BASED ENHANCEMENTS. RESULTS SERVE AS INPUT INTO SYSTEMS ECONOMIC MODELS

Ohio River Mainstem Systems Study

Where Do You Focus Limited Funding?

Failures at Certain Locks Affect Traffic in Other Areas

- Deteriorated miter gates in middle reaches of Ohio River
- Deteriorated mass concrete at 3 locks on Upper Ohio River
- Capacity upgrades needed at high-traffic projects with 600-ft auxiliary

Need for Improvements (both new and existing projects) Will Grow More Critical as Projects Age and See Increased Traffic Levels

Systems Approach with Probabilistic Economic Modeling Coupled with Engineering Reliability Analysis Provided a Method for USACE to Make Critical Infrastructure Decisions

Ohio River Mainstem Systems Study

Reliability-Based Integration

- Analytical reliability models developed for most critical components (very costly and/or significant impact to navigation traffic if failure were to occur)
- This modeling process was used to determine expected costs (both navigation and repair) associated with the future reliability of critical infrastructure
- Analysis was used to time optimal replacement date for major components that became unreliable
- Critical components determined by two phase ranking system (judgment and numerically-based)

Ohio River Mainstem Systems Study

Sample of Reliability Models Developed

Structural

- Hydraulic Steel Structures (Miter Gates, Culvert Valves, and Dam Gates)
- Concrete Structures (Mass concrete subjected to AAR)

Geotechnical/Structural

- Lock walls (anchored and unanchored)
- Approach walls
- Erosion of dam stilling basins

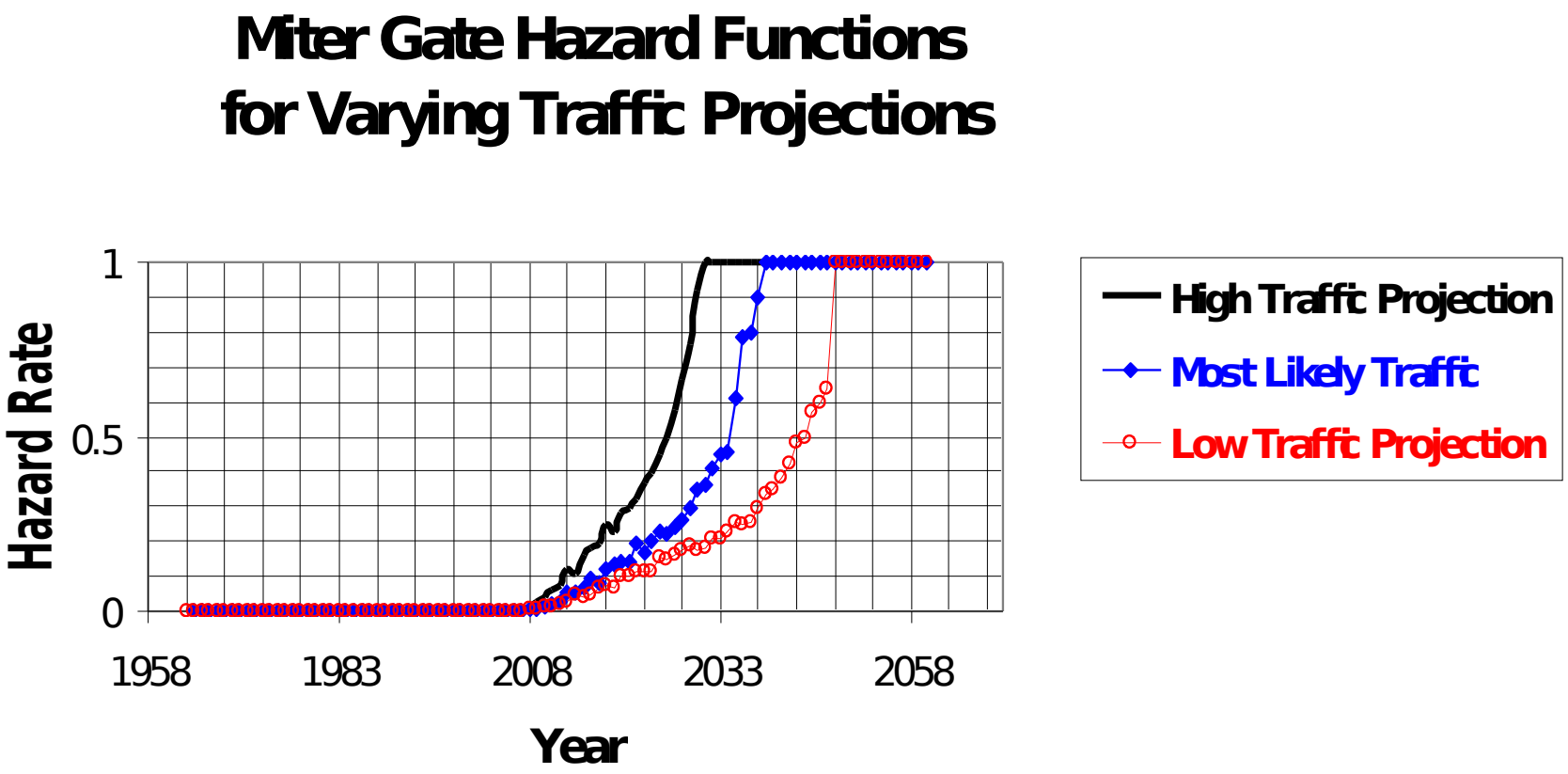
Mechanical and Electrical

- Operating machinery (gates and valves)
- Electrical systems (motors, controllers)

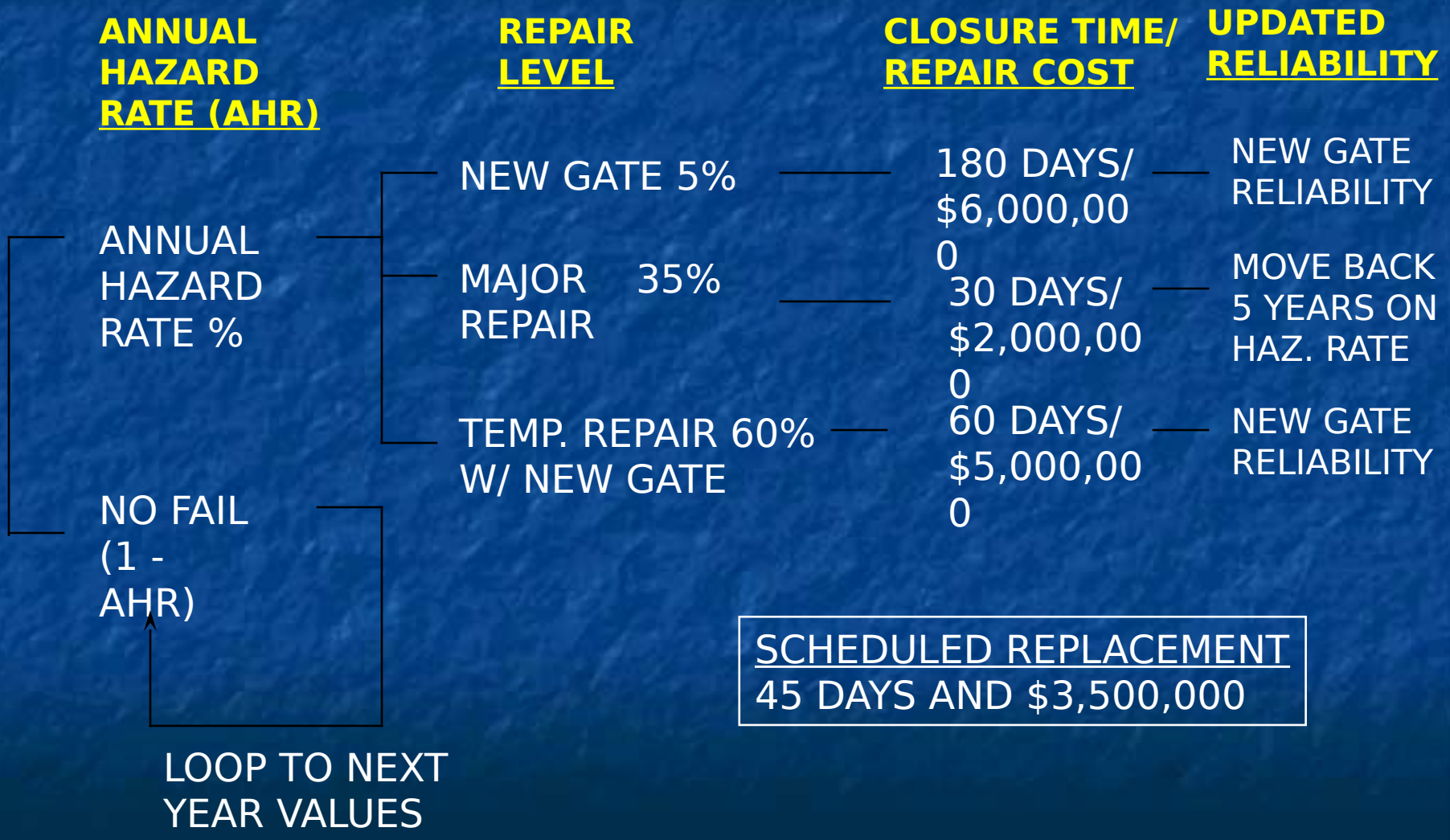
Engineering Reliability Inputs

- Annual Hazard Rate (Time Dependent)
  - Components that degrade with time (hydraulic steel structures)
- Probability of Failure (Non-Time Dependent)
  - Gravity structures whose properties do not change with time
- Event Tree for each component
  - All failures assumed significant
  - Levels of repair (Engineering Judgment)
  - Cost and Chamber Closure Times for Repair
- “Scheduled” Component Replacement Cost and Closure Duration

Hazard Functions for Forecast Traffic



Consequence Event Trees – Time Dependent Component Example



Assessment of Probabilistic Modeling

- Engineering Reliability Analysis
  - Detailed structural condition studies
  - Develop time dependent failure probabilities for critical operating components
  - Identify consequences of unsatisfactory performance (repair costs & closures)
- Economic Uncertainty Modeling
  - Simulate 50-year project life
  - Uncertainty provided through key economic drivers such as traffic forecasts and rate savings
  - Evaluate formulation alternatives

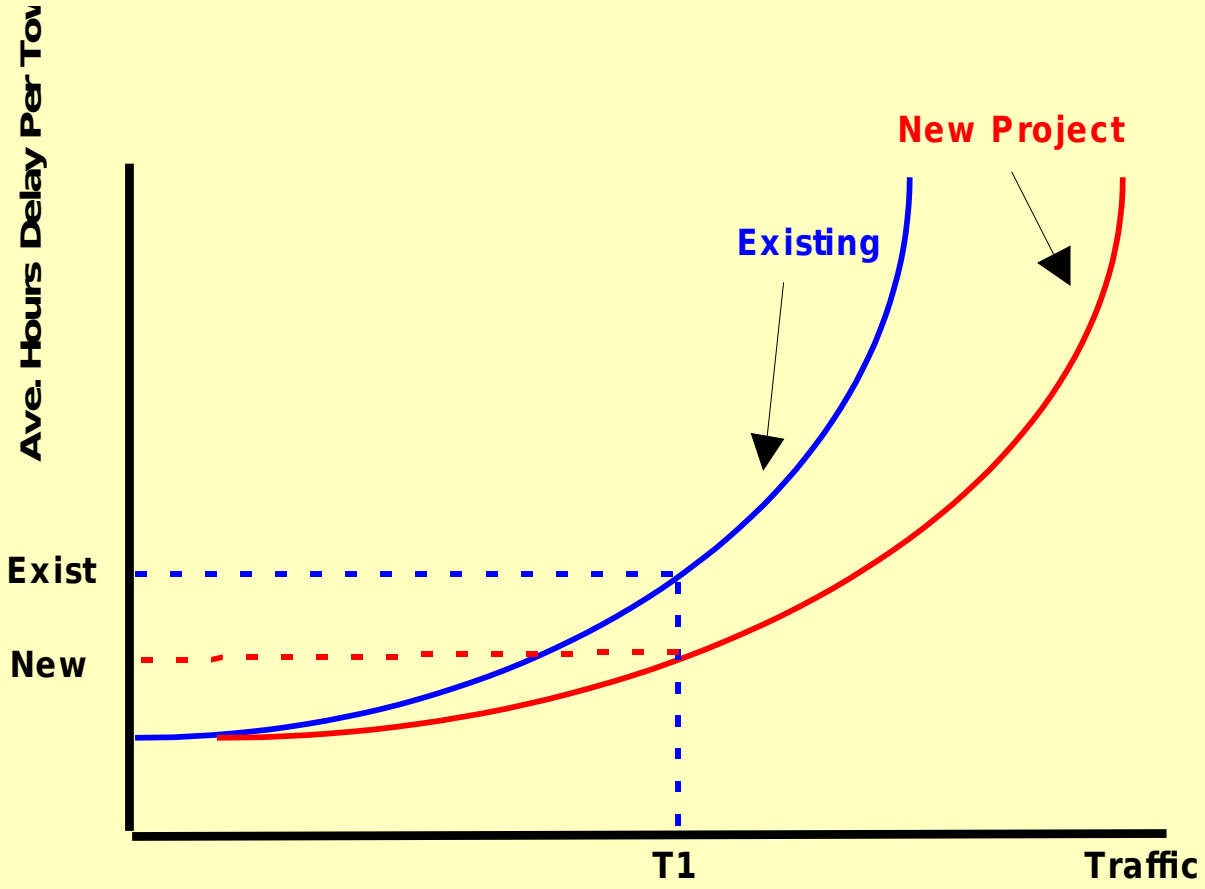
Determining Optimized W/O Condition

- Hazard functions are developed for each repair scenario and traffic forecast
  - Fix-as-Fail (Baseline Condition)
  - Advanced Maintenance
  - Scheduled “High-Level” Repair
- Consequence event trees are developed consistent with hazard function limit state
  - Based Upon Field Experience When Possible
  - Multiple Levels of Repair Developed

Benefit Estimation - Erosion of Benefits

- Increasing costs to industry erode benefits
  - Capacity constraints - leading to traffic congestion and delays
  - Degradation of service (poor reliability)
    - Aging projects closed more often and for longer periods
    - Budget constraints may cause reduced levels of maintenance and reliability
    - Greater reliance on smaller, auxiliary locks

Benefit Estimation – Improved Capacity

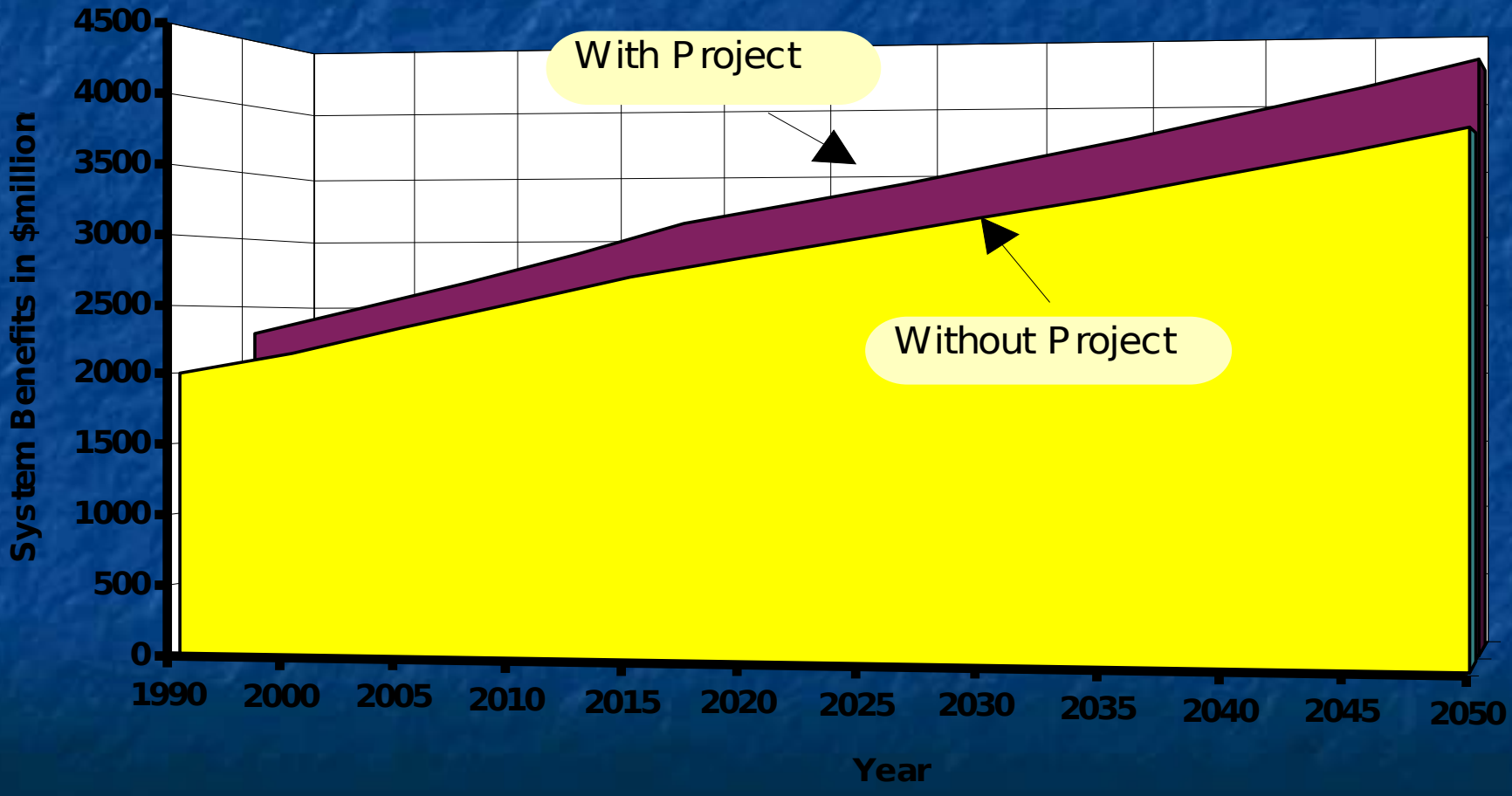


New Project

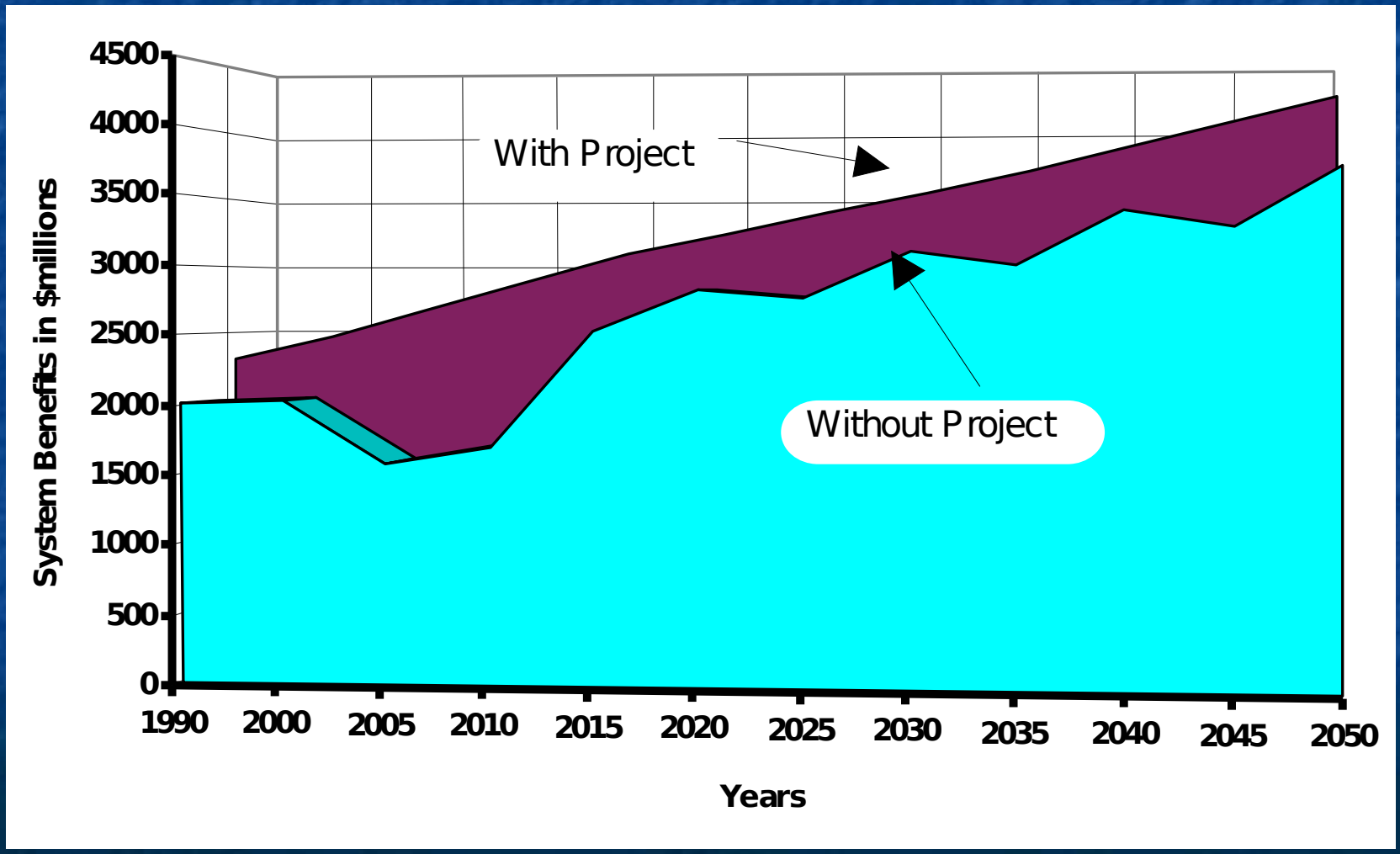
More reliable facili

Physical expansion

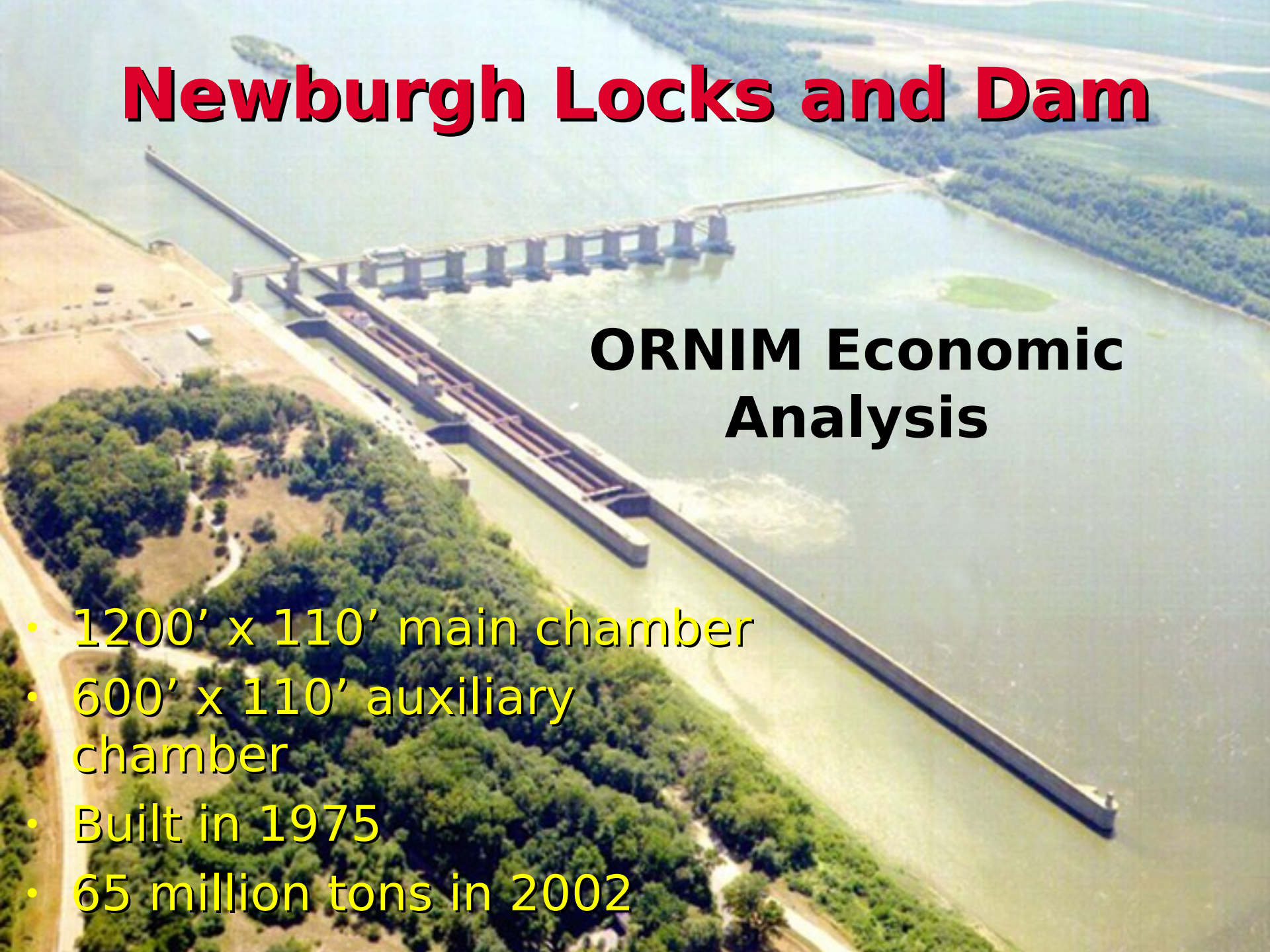
Incremental Benefits - Prior to Reliability Integration



Incremental Benefits – With Reliability Integrated



Newburgh Locks and Dam



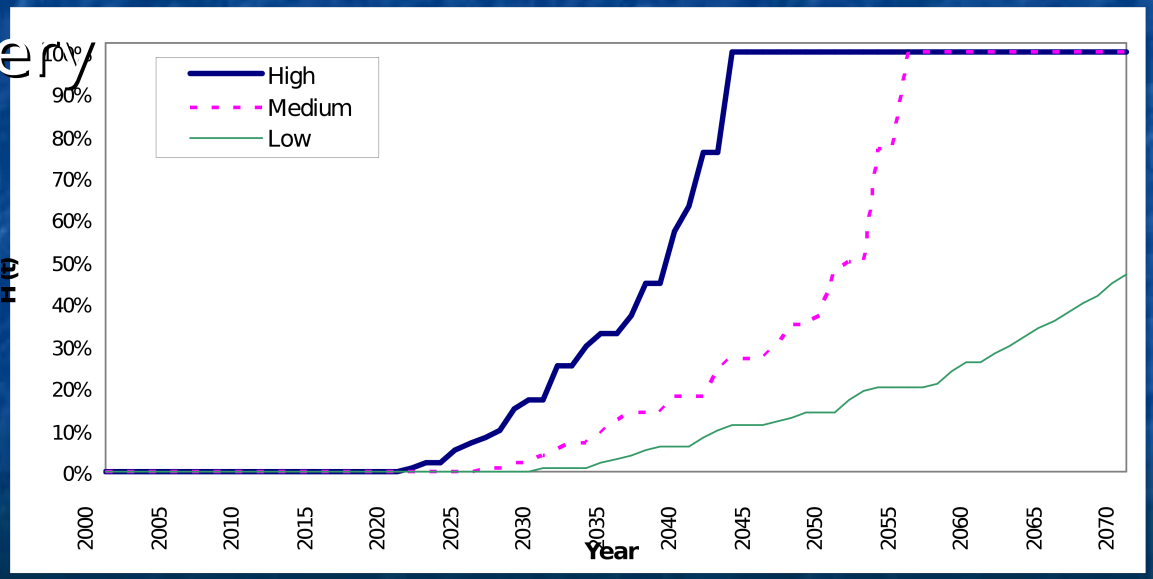
ORNIM Economic Analysis

- 1200’ x 110’ main chamber
- 600’ x 110’ auxiliary chamber
- Built in 1975
- 65 million tons in 2002

ORNIM Economic Analysis

Newburgh Components Analyzed

- Miter Gates (Upper & Lower)
- Miter Gate Machinery (Upper and Lower)
- Culvert Valves
- Culvert Valve Machinery
- Hydraulic Systems
- Electrical Systems

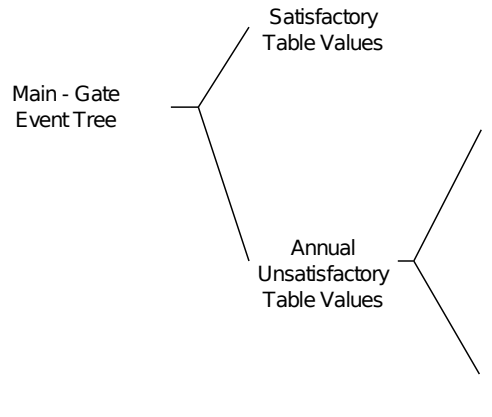


Newburgh Main Chamber Miter Gate Hazard Values for Future

ORNIM Economic Analysis

Newburgh Component Replacement Optimization

Newburgh Main Chamber Miter Gates Event Tree



Component	Annual Time Dependent Probabilities	Prob. Degree of Failure	Repair Level	Prob. Repair Level	Year of Repair	Cost	Year of Failure Closure Days	Following Year 1/2 Spd Days	Effect on Reliability
Main - Gate Event Tree	Satisfactory Table Values		New Gate	5%	1	$13,150,000	365	0	R=1 all future years
					2	$3,150,000	90	0	
	Annual Unsatisfactory Table Values	Major 100%	Major Repair	35%	1	$1,575,000	45	0	Back 5 years
					2	$1,575,000	45	0	
			Temporary Repair with New Gates 60%	60%	1	$3,575,000	45	0	R=1 all future years
					2	$3,575,000	45	0	
					3	$5,050,000	30	0	
		Minor 0%							

Scheduled Replacement Year 1 = 30 - closure days and cost $5,050,000
Year 2 = 30 - closure days and cost $5,050,000
Future Reliability will be equal to 1.0 for all future years after replacement

ORNIM Economic Analysis

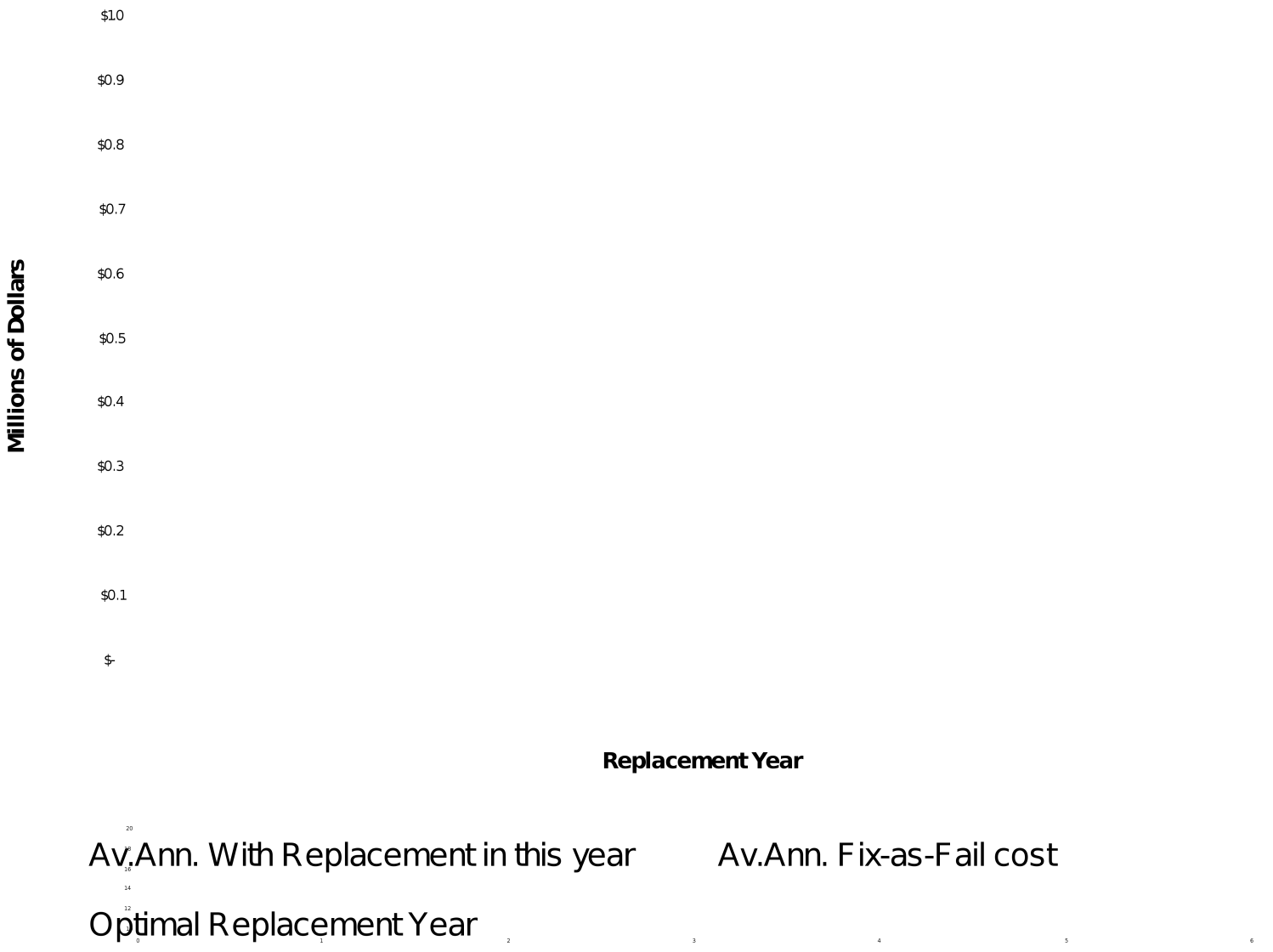
Newburgh Lock Reliability Analysis

Optimal Component Replacement

Chamber / Component	Forecast Scenario					
	Clear Skies	Clear Skies No Hg	NAAQS Flat	NAAQS Growth	Utility Based	Utility Based High
Main Chamber						
Miter Gates (Upper & Lower)	2035	2034	2034	2034	2035	2033
Miter Gate Machinery (Upper & Lower)	FAF	FAF	FAF	FAF	FAF	2058
Culvert Valves	FAF	FAF	FAF	FAF	FAF	2058
Culvert Valves Machinery	FAF	FAF	FAF	FAF	FAF	FAF
Hydraulic Systems	2015	2015	2015	2015	2026	2021
Electrical Systems	2015	2005	2005	2005	2026	2023
Auxiliary Chamber						
Miter Gates (Upper & Lower)	FAF	FAF	FAF	FAF	FAF	FAF
Miter Gate Machinery (Upper & Lower)	FAF	FAF	FAF	FAF	FAF	FAF
Culvert Valves	FAF	FAF	FAF	FAF	FAF	FAF
Culvert Valves Machinery	FAF	FAF	FAF	FAF	FAF	FAF
Hydraulic Systems	FAF	FAF	FAF	FAF	FAF	FAF
Electrical Systems	FAF	FAF	FAF	FAF	FAF	FAF

ORNIM Economic Analysis

Newburgh Main Chamber Miter Gates Optimization



Thank You !!!

Questions ???

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